Potent Proton Acceleration

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Trident was built in 1992, about 10 years before the National Academy of Sciences came up with the X-Games theme, but Trident's original mission—to support an earlier, never fully realized, national laser-induced-fusion program (ICF, for inertial confinement fusion)—was well aligned with the pursuits of many present-day X-Gamers. An upgrade completed in 2007 boosted Trident's maximum power from 30 terawatts to over 200 terawatts through the addition of the short-pulse capability. This was all Trident needed to seriously compete with other short-pulse, high-power-laser facilities.

In addition to a super-low prepulse value, the intensity of a Trident short pulse can be higher than those of more-powerful short pulses produced at other facilities. This feature has contributed to a major improvement in the method of proton-beam generation discovered with the Petawatt.

The intensity of a pulse is its power divided by the area on the target illuminated by the pulse. Trident achieves high intensity by focusing a larger fraction of a short pulse's power into a small area than can some higher-power lasers. Since the radiation pressure of a pulse is proportional to its intensity, a Trident short pulse can more effectively push a target's electrons around—the first step in accelerating protons with a light pulse (see "Proton Acceleration" box).

In addition to igniting fusion plasmas, the proton beams could also be used to treat cancerous tumors. Many different types of cancer have been successfully treated by blasting tumors with protons accelerated to about 200 million electron volts (MeV) in a circular accelerator called a cyclotron. Cyclotrons typically 12 feet in diameter are now offered commercially for proton-radiation treatment. But they could be replaced one day with much smaller and cheaper systems based on laser acceleration—in part because ultraintense short laser pulses can accelerate protons in about 1 millionth the distance required by existing accelerators to reach the same energy.

A few months ago, Trident researchers led by Kirk Flippo produced protons with an energy of 58.5 MeV—surpassing by 0.5 MeV the record set by the Petawatt but using only about one-sixth the power that the Petawatt needed. This is a significant step toward developing compact proton accelerators.

When Trident protons reached 58.5 MeV, the energy of the Trident prepulse was less than one 10-millionth that of the short pulse. However, the best proton acceleration requires a foil target that is very thin but still intact and cold when the short pulse hits it. To permit ideal conditions for proton-acceleration experiments, the Trident researchers thought about how they could reduce the prepulse energy even further.

"Randy Johnson, another of our staff members, came up with a highly effective remedy," Flippo says. The Trident "crew" successfully implemented Johnson's idea this year in early September, reducing the prepulse energy to less than one 10-billionth that of the short pulse—a thousandfold improvement that has already permitted proton-acceleration experiments with metal-foil targets as thin as 5 billionths of a meter. Other high-power lasers can use targets no thinner than 10 to 20 micrometers without destroying them (prematurely). Trident's super-low prepulse value promises to be one more significant step toward developing compact proton accelerators.

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When a Trident "short" pulse strikes a metal foil, the pulse's light is so intense that it quickly accelerates some of the foil’s electrons to nearly the speed of light. These electrons pass through the foil and a thin layer of residual water, to form a hot electron cloud near the back of the foil. The cloud's electric field ionizes the molecules in the water layer to form a plasma (not shown) of protons (hydrogen nuclei), oxygen ions, and electrons. The field also accelerates protons from the plasma, forming a beam. That proton beam, which can include some electrons from the cloud, can have energies of up to 58 million electron volts. Such proton beams can be used to ignite fusion plasmas or possibly to perform table-top nuclear physics and to treat cancerous tumors.